



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**ASSIGNMENT PROBLEM FOR THE U.S. MARINE  
CORPS: REGIONAL, CULTURE, AND LANGUAGE  
FAMILIARIZATION PROGRAM**

by

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December 2013

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**ASSIGNMENT PROBLEM FOR THE U.S. MARINE CORPS: REGIONAL,  
CULTURE, AND LANGUAGE FAMILIARIZATION PROGRAM**

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## **ABSTRACT**

The U.S. Marine Corps recently developed the Regional, Culture, and Language Familiarization Program (RCLF), which assigns newly promoted sergeants and commissioned officers to one of the 17 regions established by the RCLF office. As of now, there is no formal process established in assigning Marines to one of the 17 regions. The assignment is done manually and often by random allocation, without a standard operating procedure. We developed two integer-programming models and a matching algorithm that utilizes top trading cycle and serial dictatorship. These models optimize the assignment based on Marine and USMC preferences. We find that the benchmark integer programming model is the best in terms of assigning most Marines within their top four choices. Regardless, satisfaction rates of any of the three models are higher than the random-assignment model.

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## **I. INTRODUCTION**

### **A. REGIONAL, CULTURE, AND LANGUAGE FAMILIARIZATION PROGRAM BACKGROUND**

The Regional, Culture, and Language Familiarization (RCLF) Program is part of the Marine Corps's strategy to meet the demands of the 21st century. The need for an RCLF program was recognized in the Commandant's Planning Guidance 2010, the U.S. Marine Corps Vision and Strategy 2025, and forms the basis of the Language, Regional and Culture Strategy: 2011-2015 (MROC, 2012). The RCLF mission is "to ensure that Marines are globally prepared and regionally focused so that they are effective at navigating and influencing the culturally complex 21st Century operating environment in support of Marine Corps's missions and requirements" (MROC, 2012, p. 12).

The Marine Corps has a forward-deployed presence as part of its Marine Expeditionary Unit deployment program that enables the United States to rapidly respond to most crises around the world. While the Marine Corps has the military strength to fight in any clime and place, it comes up short in educating the Marines on the many cultures it may encounter. Based on today's conflict, most cultural training takes place to prepare Marines for an assignment in Afghanistan. Many smaller conflicts, however, are brewing in other regions of the world of which the Marines are not well versed. To close the cultural gap between current operations and smaller "hot spot" conflicts around the world, the Marine Corps established the RCLF (MROC, 2012).

The RCLF divides the world into 17 regions. The 17 regions are: Caucasus, Central Asia, Balkans, Arabian Peninsula and Gulf, Levant, North Africa, South Asia, West-South Asia, West Africa, Sahel, East Africa, Central Africa, Southern Africa, North East Asia, Southeast Asia, Central America and Caribbean Basin, and South America. Each region is assigned a percentage of the force. The less volatile regions have a smaller requirement than current "hot spots." The percentage is subject to change based on Marine Corps's current and future operations. The 17 regions are represented by nine core languages: Arabic, Russian, French, Spanish, Portuguese, Farsi, Korean, Chinese, and Urdu. The entire scope of the RCLF program is depicted in Appendix A.

Considerations are given to increasing the RCLF program into 22 regions in the future, as well as adding additional languages.

Marine officers and enlisted Marines starting at the grade of sergeant will be assigned one of the 17 regions so they can begin career-long, culture-specific education and language familiarization. The program is not designed to make every Marine a cultural expert or a linguist, but to provide Marines with a “rudimentary understanding of the unique characteristics associated with a particular region” and to “provide language familiarization in the employment of tactical phrases” (MROC, 2012, p. 5).

Participation in the RCLF program is mandatory and it will be considered a requirement for promotion (MROC, 2012). A Marine will not be considered Professional Military Education (PME) complete until he/she completes an RCLF block for rank. The RCLF curriculum is divided into training blocks. There are five training blocks for the officer corps and seven training blocks for the enlisted corps. Figures 1 and 2 depict the blocks and applicable grades. As seen in the figures, the learning objectives build on each other over a Marine’s career to achieve regional understanding that complements the Marine’s anticipated role in the conflict.



Figure 1. Officer Program (from MROC, 2012, p. 36)



Figure 2. Enlisted Program (from MROC, 2012, p. 37)

## **B. THE ASSIGNMENT PROCESS**

No formal assignment process is used in the RCLF region selection for officers or enlisted Marines. Enlisted Marines are assigned randomly shortly after their promotion to sergeant. Alfred Ortega in the Marine Corps Manpower and Reserve Affairs Division assigns the enlisted Marines to their regions. Ortega uses a C+ program he wrote to determine the number of Marines to be allocated to each region based on the population size and required allocation for each region (personal communication, May 9, 2013). Once Ortega's program determines how many Marines will be assigned to each region, he starts at the top of the list and makes his way down until each Marine is assigned a region (personal communication, 2013). Marines are given choice only by exception on a case-by-case basis. The decision to assign Marines randomly stems from the difficulty in collecting Marines' preferences and the lack of a computerized program to make the assignment. A manual process is unrealistic since every month 600–700 Marines are promoted to sergeant (Ortega, 2013). A computer-based program would simplify the assignment process.

The assignment process at The Basic School varies by each student company. According to The Basic School, some student companies allow Marine officers to voice their preferences, while other companies assign Marines randomly. A student company averages 250 officers. The process of taking 250 preferences into consideration is still cumbersome and manpower-intensive.

When Marine officers were questioned about their preference for assignment, the majority indicated that they would prefer to be given choice during the assignment process. Although the sergeant population has not been sampled about their preferences, Kerry Fosher from the RCLF office indicated that the enlisted Marines, if given the choice, would also prefer to rank their preferences (personal communication, May 9, 2013). Because there are inconsistencies in assignments between officers and enlisted, as well as within the officer population, this thesis will look at improving the current process to allow each Marine to state his or her preference.

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## **II. LITERATURE REVIEW**

Various optimization models and matching algorithms have recently been developed to improve the assignment process. An integer programming (IP) model can be a useful method in simplifying an assignment process. According to Ross and Soland (1975), the “purpose of the classical assignment problem and many variations on it is to find optimal pairings of agents and tasks” (p. 91). An IP model can be superior to a random assignment model in many aspects. IP models may be Pareto efficient but may not be transparent. Transparency can be improved by using a different type of matching algorithm, such as the top trading cycle or serial dictatorship. We will design a series of assignment models and measure their performance by ability to be Pareto efficient, fair utilizing standard deviation, strategy proof, transparent, and have economy of scale.

### **A. ASSIGNMENT PROBLEM AND PARETO EFFICIENCY**

The random assignment process can lead to inefficiency because there can be better pairings made between people and tasks. If the Marine Corps wants to produce culturally savvy Marines, it should take their preferences into considerations in order to obtain better pairings. According to Reinhardt (1992), “the most popular concept of efficiency used by economists, mainly in abstract theory or in the class room, is one first formulated by the nineteenth- century economist Vilfredo Pareto” (p. 306). Reinhardt’s (1992) article further defines Pareto efficiency as “an efficient allocation of resources is one from which no person can be made to feel better off without making another person feel worse off” (p. 307).

Random assignment lacks Pareto efficiency. To consider an assignment process efficient, “it is not possible to make an agent better off without making another agent worse off” (Kesten, 2006, p. 158). In order for an assignment to be fair, the matching has to have “the fewest number of unmatched customers (i.e., it has maximum-cardinality), and subject to this, matches the fewest number of customers to their  $n$ th-ranked item, and subject to this, matches the fewest of customers to their  $(n-1)$ th-ranked item, and so on” (Abraham, Chen, Kumar, & Mirrokni, 2006, p. 3). We will use mean and standard

deviation to determine the fairness of the model using Abraham et al.'s idea that we want to have the fewest unmatched Marines and fulfill the Marine's highest nth ranking.

In an assignment problem, one side has a preference over the objects, but the objects themselves do not care who is assigned to them. A problem closely related to the RCLF assignment is described in Abraham, Chen, Kumar, & Mirrokni. Abraham et al. (2006) apply the matching model to a rental market where the customers have preferences over movies, but movies do not have preferences over which customer rents them. The rental market is restricted by the number of copies available for each movie. The problem is further complicated by the non-uniformity in movie popularity. Some movies, such as recently released blockbusters, tend to be more popular than older movies. In case of the RCLF regions, some languages are more popular than others, making the assignment problem complex.

In the study by Abraham et al., the one-sided matching assigned one movie to a customer using a valuation function of six theoretical frameworks, weighted matching, rank-maximal matching, weighted rank-maximal matching, fair matching, order-based matching, and stable matching. The valuation functions were then applied to three models representing different ways a movie can be allocated. The fair matching valuation function, where there are the fewest unmatched customers and fewest matches to nth choice, obtained the best results.

## **B. DECISION MODELING IN ASSIGNMENT PROBLEMS**

Balakrishnan, Render and Stair (2012) define decision modeling as “a scientific approach to managerial decision making” whose goal is the “development of a model (usually mathematical) of a real-world problem scenario or environment” (p. 2). A model is not skewed by human emotions, personal bias, hasty solutions, or guesswork. Decision modeling is used in a variety of situation, ranging from business, government, health care, or education.

According to Ross and Soland (1975), an assignment problem is subjected to a mathematical formulation function. The mathematical function can be accompanied by constraints to meet assignment requirements, such as only a certain number of people can

be assigned to any one job. Since the assignment of workers to jobs cannot be done in fractions—one cannot have 1.5 workers assigned to a job—the decision model is specified as an integer programming model using general integer variables. If an integer programming model requires a decision, such as yes, a Marine will be assigned to a region, or no, a Marine will not be assigned, binary variables capture the decision between the two choices.

To solve an assignment problem, Balakrishnan et al. (2012) recommends formulating the problem as a transportation model with supply and demand nodes with the objective to “find the least-cost solution that uses the one-unit supplies at the origin nodes to satisfy the one-unit demands at the demand nodes.” Liang and Thompson (1987) from the Navy Personnel Research and Development Center pioneered the transportation model and other network flow models to solve a large-scale personnel assignment model for the Navy.

According to Liang and Thompson (1987), using personnel assignment models in the U.S. military goes back to the early 1960s. “In the mid-1970s, a technological breakthrough occurred in the computational capability of network optimization techniques” (Liang & Thompson, 1987, p. 235) enabling researchers to solve large-scale models. Given the computing capability available today, the U.S. military should take advantage of the situation and utilize the modern capability to run assignment models in situation where manual processing still takes place.

### **C. TOP TRADING CYCLE**

Top trading cycle is based on the work of David Gale. Kesten (2006) describes Gale’s top trading cycle algorithm as follows:

Initially, each object is assigned to a different agent. Each object “points to” the agent it is assigned to and each agent points to his favorite object. If the null object is the favorite object of an agent, then he points to himself and constitutes a self-cycle. Since the number of agents and the number of objects are finite, there is at least one cycle. Then in each cycle, the corresponding trades are performed, i.e., each agent in the cycle is allotted the object he points to and these agents and objects are removed.

Then the same procedure is applied to the reduced market and so on. The algorithm terminates when there are no agents or objects left (p. 160).

The top trading cycle (TTC) approach was recommended by Abdulkadiroğlu, Pathak, Roth, and Sönmez (2005) in the case of assigning students to schools in the Boston Public Schools system. The top trading cycle allows students to trade their priority at one school with a student at another school. The top trading cycle would allow Marines to trade regions and obtain the choice they would prefer, making the overall regional assignment process Pareto efficient.

Roth, Sönmez, and Unver (2004) adapted the top trading cycle from the housing market design to the exchange of kidneys. Because most kidneys are received from cadavers, there is a significant shortage of kidneys available for transplantation. Live kidney donors are also in limited supply and, as a result, many people die or become too ill to undergo transplantation. Roth et al. argues that adapting the TTC to the kidney exchange can help alleviate some shortage of organs and improve patient welfare by organizing the exchanges to achieve efficiency.

Unlike the housing allocation problem, in the kidney exchange it is not known how many kidneys maybe available. To adapt the TTC to the kidney exchange, Roth et al. added a cycle consisting not only of an exchange, but also of a waiting list. The modified trading cycle mechanism proposed for the kidney exchange improves the quality of the matches, reduces competition for kidneys, and benefits more patients.

The top trading cycle is popular in market design because it can be Pareto efficient and strategy proof when making assignments such as students to schools, housing, or patients to kidneys based on priorities. TTC allows students or patients to trade their priorities to receive a more preferred choice.

Noah Myung (2005) describes the top trading cycle for school seat allocations as follows:

$\underline{s_1}$	$\underline{s_2}$	$\underline{s_3}$	$\underline{s_4}$		$\underline{i_1}$	$\underline{i_2}$	$\underline{i_3}$	$\underline{i_4}$	$\underline{i_5}$	$\underline{i_6}$	$\underline{i_7}$	$\underline{i_8}$
$i_1$	$i_3$	$i_5$	$i_6$		$s_2$	$s_1$	$s_3$	$s_3$	$s_1$	$s_4$	$s_1$	$s_1$
$i_2$	$i_5$	$i_3$	$i_8$		$s_1$	$s_2$	$s_2$	$s_4$	$s_3$	$s_1$	$s_2$	$s_2$
$i_3$	$i_4$	$i_1$	$i_7$		$s_3$	$s_3$	$s_1$	$s_1$	$s_4$	$s_2$	$s_3$	$s_3$
$i_4$	$i_8$	$i_7$	$i_4$		$s_4$	$s_4$	$s_4$	$s_2$	$s_2$	$s_3$	$s_4$	$s_4$
$i_5$	$i_7$	$i_2$	$i_2$									
$i_6$	$i_2$	$i_8$	$i_3$									
$i_7$	$i_1$	$i_6$	$i_5$									
$i_8$	$i_6$	$i_4$	$i_1$									

School 1 and 2 have two seats and 3 and 4 have three seats

Top trading cycles

Denote  $c_{s_i}(k)$  be the counter for steps  $s_i$  at step k.

Step 1:  $c_{s_1}(1) = 2$ .  $c_{s_2}(1) = 2$ .  $c_{s_3}(1) = 2$ .  $c_{s_4}(1) = 2$ .

Two cycles in step 1:  $(s_1, i_1, s_2, i_3, s_3, i_5)$  and  $(s_4, i_6)$ .

So students 1, 3, 5, and 6 are assigned a seat and schools 1, 2, 3, and 4 decreases its counter by 1.

Step 2:  $c_{s_1}(2) = 1$ .  $c_{s_2}(2) = 1$ .  $c_{s_3}(2) = 2$ .  $c_{s_4}(2) = 2$ .

The only cycle is  $(s_1, i_2)$ .

Step 3:  $c_{s_1}(3) = 0$ .  $c_{s_2}(3) = 1$ .  $c_{s_3}(3) = 2$ .  $c_{s_4}(3) = 2$ .

The only cycle is  $(s_3, i_7, s_2, i_4)$ .

Step 4:  $c_{s_1}(4) = 0$ .  $c_{s_2}(4) = 0$ .  $c_{s_3}(4) = 1$ .  $c_{s_4}(4) = 2$ .

The only cycle is  $(s_4, i_8)$ .

Algorithm now comes to a stop.

Hence the match is:

$$\mu_{TTS} = \begin{pmatrix} i_1 & i_2 & i_3 & i_4 & i_5 & i_6 & i_7 & i_8 \\ s_2 & s_1 & s_3 & s_3 & s_1 & s_4 & s_2 & s_4 \end{pmatrix}$$

#### **D. SERIAL DICTATORSHIP**

Another matching mechanism in allocation problems is the simple serial dictatorship or the random serial dictatorship. In a serial dictatorship agents are assigned an order and they chose their preferences in that order. Serial dictatorship is often used in college dorm allocation. The first student on the list will receive his/her first choice. The next student on the list will then receive his/her highest choice from the remaining supply of houses, and so on. Simple serial dictatorship, however, can discriminate among students. For example, if you show up first in line, you receive higher priority. Random serial dictatorship eliminates that discrimination by randomly assigning an order to students in which they can pick their preferences.

In a simple serial dictatorship, Abdulkadiroğlu and Sönmez (1998) further state, “agent  $f(1)$  always gets his top choice whereas agent  $f(n)$  gets whatever is remaining after everyone else has chosen” (p. 692). Because agent  $f(n)$  has to choose from the remaining choices, simple serial dictatorship is less desirable for assignment problems. Because the order to agents is randomly assigned, random serial dictatorship is considered Pareto efficient. Since the agents do not know how they will be assigned, concealing their preference is not to their advantage. As such, random serial dictatorship is also considered to be strategy-proof.

The advantage of serial dictatorship is that it can be easily applied. This is especially relevant to the RCLF assignment where the assigned population varies from about 250 to 700 Marines.

#### **E. RELATED WORK**

Several master’s theses have been written at the Naval Postgraduate School that provide a good reference for the assignment process. Two of these works are summarized within this thesis. Both theses support the argument that integer programming can improve various assignment processes and reduce manpower associated with manual assignments.

## **1. Equitably Distributing Quality of Marine Guards Using Integer Programming**

In his master's thesis, Jonathan Sabado (2013) utilized an integer programming model to equitably distribute the quality of Marine security guards across nine regions. Sabado used a non-linear integer programming assignment model with an objective function to minimize the sum of squared differences of average quality among the regions. Because Excel software is limited to 200 variables and constraints, Sabado used the Premium Solver Platform for his model. The Premium Solver Platform can execute up to 2,000 decision variables. Even then, Sabado's model was too large for Solver, and he was forced to split his model into thirds. While splitting the modeling into three sections did not take away from Sabado's model, it highlighted the limitations of available software to run large scale models. It is likely that the RCLF assignment model will encounter the same problem if a robust solver engine is not available.

Sabado developed four distinct models for his assignment problem. Each model took into consideration different criteria imposed by the decision maker. Model 1 was based on the minimize function of squared differences of average quality among the regions. Model 2 used recommendation as the primary constraint. Model 3 used recommendation and security level value for rank, experience, and MSG rating as a constraint. Model 4 was similar to Model 1, but had a minimum threshold value for recommendation, rank, experience, and MSG rating.

Sabado addressed several limitations in his study, with the most important being the Excel limitation to run sizeable models. The second limitation was subjectivity of each category and the weighted attribute assigned within each model. Despite the limitations, Sabado (2013) concluded that each model was feasible for implementation and would help to "quantify the quality of MSG assignments" (p. 6). It would be up to each decision maker to decide which model they would use based on their preferences for assignment criteria.

## **2. Optimizing Marine Security Guard Assignments**

In his 2011 master's thesis at the Naval Postgraduate School, Marco Enoka set the foundation for research on assigning Marines to MSG duty. Enoka set out to compare the manual assignment process with a Marine Security Guard Assignment Tool (MSGAT), an Excel-based program that utilizes integer linear programming to assign Marines to MSG regions. MSGAT algorithm is based on a two-layer multi-commodity network model. The variables or commodities within the model are based on the requirements for assignments to the various MSG duty stations, such as rank, experience, duty preference, or gender.

Prior to developing the MSGAT, the assignment personnel would have to manually assign from 1,200 to 1,500 enlisted Marines to MSG billets. The manual process produced feasible solutions, but it was labor intensive and the quality of the assignments was not guaranteed.

In his thesis, Enoka (2011) compared the MSGAT assignments to actual manual assignments to assess the performance of the MSGAT tool. In almost all instances, MSGAT tool provided superior results to the manual assignment. Enoka (2011) concluded that "MSGAT assignments provide solutions that result in a higher overall satisfaction level than manually generated assignments" (p. 58). Not only did the MSGAT tool provide superior assignments, it shortened the assignment process from 1,200 hours to a 12-hour data input period and 30 seconds of computer run time to produce the assignments.

### III. MODEL, MATERIALS, AND METHODS

#### A. INTRODUCTION

Model development, materials, and methods for each model used are reviewed in this chapter. The models are defined in terms of a mathematical model, variables, and problem parameters. The materials and methods section describes the subject population, data gathering, software used, and survey development.

#### B. MODEL DESCRIPTION—MODEL I: BENCHMARK IP MODEL

##### 1. Benchmark IP Model Description

We will be using the integer programming model. All parameters of our model are deterministic.

The goal of the model is to optimally assign Marines to RCLF regions based on the Marine's preference. Optimally, for the purpose of this study, is defined as most Marines receiving their top choice for region assignment. Since the demand for regions can and likely will exceed supply of quotas, it is not possible for every Marine to receive his/her first choice. It is better, however, to receive a second or third choice over a 15th or 17th choice.

The model consists of Marines' preferences (demand), constraints based on the available supply of regional quotas (supply), and decision variables in the form of binary numbers to indicate an assignment to region. The model also has a constraint indicating that each Marine has to be assigned to one region only.

##### 2. Benchmark IP Model Development

###### a. Variables

The optimization model used the following variables:

$$x_{m,r} = \begin{cases} 1 & \text{if Marine } m \text{ is assigned to region } r \\ 0 & \text{otherwise} \end{cases}$$

where  $m = \{1, 2, 3, \dots, M\}$  and  $r = \{1, 2, \dots, 17\}$  (1)

Define  $P_m \in \mathbb{R}^{17}$  be a vector where the  $n$ th component is preference ranking of Marine  $m$  for region  $r$ . Each component in  $P_m, P_m = (p_{m,1}, \dots, p_{m,r}, \dots, p_{m,17})$  must be a natural number between 1 through 17, where lower number represents higher preference. The entries in the vector need to be unique.

$s_r \in \mathbb{R}_+$  is the supply of quotas for region  $r$ . (1)

Out of the  $M$  Marines,  $s_r$  percent must be assigned to region  $r$ .

The current quota for each of the  $s_r$  is:

1. Trans-Caucasus	3%
2. Central Asia	5%
3. The Balkans	3%
4. North Africa	4%
5. The Levant	3%
6. Arabian Peninsula & Gulf	15%
7. West South Asia	12%
8. South Asia	6%
9. Western Africa	5%
10. The Sahel	4%
11. Eastern Africa	10%
12. Central Africa	3%
13. Southern Africa	3%
14. Northeast Asia	10%
15. Southeast Asia	6%
16. Central America & Caribbean	4%
17. South America	4%

Since percentage allocation can result in decimal points, the number is rounded either up or down to the nearest whole number so the total of all quotas equals the size of the Marine population. The rounding for each region is done manually,

therefore, we denote  $s'_r$  as the number of Marines region  $r$  requires. (3)

We denote  $P(x_{m,r})$  as the objective function to minimize.

***b. Objective Function***

Minimize the sum of preference ranking

$$P = \sum_{x_{m,r}}^M \sum_{r=1}^{17} p_{m,r} x_{m,r} \quad (4)$$

***c. Constraints***

Each Marine is only assigned to one region (demand constraint)

$$\sum_{r=1}^{17} x_{m,r} = 1 \quad \text{For all } m \quad (5)$$

Each region is allocated the proper number of Marines (supply constraint)

$$\sum_{m=1}^M x_{m,r} = s'_r \quad \text{For all } r \quad (6)$$

See Appendices C and D for model set up and description.

***d. Limitations***

The model has limitations caused by the mathematical function. The first limitation is due to the objective function. The objective function can be minimized by assigning Marine  $m = 1$  to region 1 or Marine  $m = 2$  to region 2 and vice versa. Because the objective of the function is to minimize the sum product of all the assignments, there are less Marines assigned their first choice, but more Marines assigned within their top five choices. Another limitation is because of the FrontLine Solver algorithm. The algorithm provides a solution, but warns that “the integer solution found may actually be the true integer optimal solution; but the Branch & Bound method did not take the extra time to search all possible remaining subproblems to prove optimality for this solution.” That means that that could be other solutions, but the one provided is within the program's acceptable error.

## C. MODEL DESCRIPTION—MODEL II OPTIMIZATION WITH USMC PREFERENCES

### 1. Optimization with USMC Preferences Description

Model II—Optimization with Marine Corps stated preferences are based on Model I, but it has an added constraint. The goal of the model is to optimally assign Marines to RCLF regions based on the Marine's preference while taking the Marine Corps stated preference into consideration. The Marine Corps stated preference is defined as giving preference to a Marine who is fluent in one of the core languages over a Marine who has no language knowledge.

Optimization with USMC preferences still consists of Marines' preferences (demand), constraints based on the available supply of regional quotas (supply), and decision variables in the form of binary numbers to indicate an assignment to region. The model also has a constraint indicating that each Marine has to be uniquely assigned to one region.

### 2. Optimization with USMC Preferences Development

#### a. Variables

The optimization model used the following variables:

$$x_{m,r} = \begin{cases} 1 & \text{if Marine } m \text{ is assigned to region } r \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

where  $m = \{1, 2, 3, \dots, M\}$  and  $r = \{1, 2, \dots, 17\}$ .

Define  $P_m \in \mathbb{R}^{17}$  be a vector where the  $n$ th element is preference ranking of Marine  $m$  for region  $r$ . Each element  $p_{m,r}$  must be a natural number between 1 through 17, where lower number represents higher preference. The entries in the vector need to be unique.

$$s_r \in \mathbb{R}_+ \text{ is the supply of quotas for region } r. \quad (8)$$

The current quota for each of the  $s_r$  is:

1. Trans-Caucasus	3%
2. Central Asia	5%
3. The Balkans	3%
4. North Africa	4%
5. The Levant	3%
6. Arabian Peninsula & Gulf	15%
7. West South Asia	12%
8. South Asia	6%
9. Western Africa	5%
10. The Sahel	4%
11. Eastern Africa	10%
12. Central Africa	3%
13. Southern Africa	3%
14. Northeast Asia	10%
15. Southeast Asia	6%
16. Central America & Caribbean	4%
17. South America	4%

Since percentage allocation can result in decimal points, the number is rounded either up or down to the nearest whole number so the total of all quotas equals to the size of the Marine population. The rounding for each region is done manually.

Therefore, we denote  $s'_r$  as the number of Marines region  $r$  requires.

Model II requires additional notations.

First,  $u_{r,m} = \begin{cases} 1 & \text{if } m \text{ speaks a language} \\ 0 & \text{otherwise} \end{cases}$  is the region  $r$ 's preference for Marine  $m$ . (9)

Next,  $w_{m,r} = \begin{cases} 1 & \text{if } p_{m,r} = u_{r,m} = 1 \\ 0 & \text{otherwise} \end{cases}$  are the mutual first choices by the region and the Marine. (10)

The number of mutual first choice capacity is therefore computed as:

$$s_r'' = \begin{cases} \sum_{m=1}^M w_{m,r} & \text{if } \sum_{m=1}^M w_{m,r} \leq s_r' \\ s_r' & \text{if } \sum_{m=1}^M w_{m,r} > s_r' \end{cases} \quad \text{the number of mutual first choices that can be assigned to a region } r . \quad (11)$$

We denote  $P(x_{m,r})$  as the objective function to minimize.

### ***b. Objective Function***

Minimize the sum of preference ranking

$$P = \sum_{x_{m,r}} \sum_{m=1}^M \sum_{r=1}^{17} [p_{m,r} + w_{m,r}] \times x_{m,r} \quad (12)$$

### ***c. Constraints***

Every Marine is uniquely assigned to only one region (demand constraint)

$$\sum_{r=1}^{17} x_{m,r} = 1 \quad \text{For all } m \quad (13)$$

Each region is allocated the proper number of Marines (supply constraint)

$$\sum_{m=1}^M x_{m,r} = s_r' \quad \text{For all } r \quad (14)$$

Mutual first choice constraint<sup>1</sup>

$$\sum_{m=1}^M \sum_{r=1}^{17} w_{m,r} x_{m,r} = \sum_{r=1}^{17} s_r'' \quad (15)$$

See Appendices E and F for model set up.

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<sup>1</sup> This constraint as stated only works in conjunction with the other constraints in this IP. A proper way to denote the mutual first choice constraint is:  $\sum_{m=1}^M w_{m,r} x_{m,r} = s_r''$  for all  $r$ . The results, however, will not change.

***d. Limitations***

The limitations for Model II Optimization with USMC preferences are same as those of Model I Benchmark IP.

**D. MODEL DESCRIPTION: MODEL III TOP TRADING CYCLE AND SERIAL DICTATORSHIP**

**1. Top Trading Cycle and Serial Dictatorship (TTC/SD) Description**

The goal of the top trading cycle model is to match Marines and Marine Corps stated preferences with the Marine's preference being the driving factor. The TTC has the same properties as the previous two models. TTC consists of Marines' preferences (demand), constraints based on the available supply of regional quotas (supply), and the Marine Corps stated preferences.

There was no computer model available to perform TTC and, as such, the assignment using TTC was done by hand. Since the TTC is used for a two-sided matching, once the regional preferences were exhausted, serial dictatorship was applied to the remainder of the officers.

**2. TTC/SD Development**

***a. Model***

As discussed in the literature review, TTC enables Marines to trade priorities for assignments with a Marine who has a higher priority for the region. We formally define TTC as the following:

Denote  $R$  as set of regions, where  $R = \{1, \dots, r, \dots, 17\}$

$M$ : set of Marines, where  $M = \{1, \dots, m, \dots, M\}$

$P$ : set of strict preferences where  $p_m \in \mathbb{R}^{17}$

Number of spaces for each region is equal to number of Marines  $\sum_{r=1}^{17} s'_r = M$

Finally, TTC is a matching  $\mu: R \rightarrow M$ . We start with a region  $r$ . A region  $r$  points to a Marine  $m$  it prefers. If that Marine prefers that region, then the Marine points to himself/herself and the self-cycle is complete. If a Marine has a preference for a

different region, he/she points to that region. That region will point to the Marine with the highest priority. If that Marine has a preference for that region, the cycle completes. If not, the Marine will then point to its desired region. That region will then point to the Marine with a highest priority if there was no self-cycle and so on, until the cycle completes with either a Marine assigned to a region or, if a region points to a Marine who points to a region without preference, the cycle terminates. This is different than the traditional top trading cycle because not all regions have preferences over Marines therefore the assignment process terminates before all Marines are assigned.

For serial dictatorship, let ordering  $f \in \mathbb{R}^M$ ,  $f = (f_1, \dots, f_m)$  be a ranking of all Marines. In serial dictatorship, the first element in  $f$ , which is  $f_1$ , denotes the first Marine that will get his/her top choice out of all the available regions. Then the second element, Marine  $f_2$ , will get his top choice out of the available regions. This continues until all Marines are assigned to a region. Note that some Marine  $f_i$  could have been assigned a region during the TTC. If such is the case, then we modify the SD so that we skip over Marine  $f_i$  and move on to  $f_{i+1}$ .

#### ***b. Utilization of the Model***

As in Optimization with USMC preferences model, language skills were used as the USMC stated preference over Marines to enable the two-sided matching. In instances where no Marine spoke the required language, the region was considered as not having a preference over an officer. Likewise, if a Marine did not possess the required language skill, the Marine was not given a priority for assignment until Marines with language skills were assigned to that region. In all cases, the officer's preference took priority over a USMC stated preferences. Otherwise the assignment process would not take Marine's preference into consideration.

Since there is a finite number of regions and Marines, there is at least one cycle in the assignment process. Each Marine and region can be part of at most one cycle. If a student is assigned to a region during a cycle, the quota from that region is removed.

When the quota reaches zero, the region is removed completely from the matching process.

Top trading cycle is applied to two-sided matching problems. Therefore, in the RCLF assignment process, it was applied only to the portion where regions had preferences over Marines who spoke a language. In our case, 20 matches were completed using TTC. Once all top trading cycles concluded based on regions' preferences, the TTC was replaced by random serial dictatorship assignment. The 49 Marines that were not assigned during the TTC were randomly assigned an order  $f$  using the random number generator. Marines would then pick their preference in the assigned order  $f$  by pointing to their next choice among the remaining available regions.

In TTC, denote  $C_r(k)$  be the counter for  $r$  at step  $k$ . For example, in our cycle, we had:

Step 1:  $C_{r=1}(1) = 2$ .  $C_{r=2}(1) = 3$ .  $C_{r=3}(1) = 1 \dots \dots C_{r=17}(1) = 3$   
 $r = 1 \rightarrow m = 41 \leftrightarrow r = 3$

One cycle in step 1: ( $r = 3$ ,  $m = 41$ ). So Marine 41 is assigned a seat and region 3 decreases its counter by 1.

Step 2:  $C_{r=1}(2) = 2$ .  $C_{r=2}(2) = 3$ .  $C_{r=3}(2) = 1 \dots \dots C_{r=17}(2) = 3$   
 $r = 1 \rightarrow m = 68 \rightarrow r = 5 \rightarrow m = 17 \leftrightarrow r = 4$

Only cycle in step 2: ( $r = 4$ ,  $m = 17$ ). So Marine 17 is assigned a seat and region 4 decreases its counter by 1, and so on.

Since TTC was set up for regions to only accept Marines who speak one of the core languages, there is one cycle in each step for a total of 20 steps. The complete list of steps and cycles for platoons 3 and 4 is in Appendix G.

When the top trading cycle terminated after 20 steps, the serial dictatorship assignment process began. To simplify the process, the remaining 49 Marines were assigned the following ordering: ( $f \dots f_n$ ) utilizing the random number generator in Excel. The ordering is: {42, 179, 7, 9, 98, 154, 126, 97, 221, 28, 46, 39, 92,

36, 165, 176, 35, 199, 183, 120, 21, 115, 200, 93, 12, 45, 77, 103, 158, 75, 222, 210, 131, 68, 145, 43, 206, 96, 118, 147, 167, 212, 207, 31, 196, 95, 86, 209, 205}, with Marine 42 being the first and Marine 205 being the last Marine in the ordering.

In our ordering, the first Marine to pick was  $m = 42$ . First choice for Marine  $m = 42$  was region 10, The Sahel. Region  $r = 10$  has 3 quotas so  $m = 42$  is assigned to  $r = 10$ . The next Marine,  $m = 179$ , had a first choice of region 13. Region  $r = 13$  has 2 quotas so  $m = 179$  is assigned to  $r = 2$ . For example, in case of Marine  $m = 45$ , first choice of Region 14, Northeast Asia, was not available. Marine  $m = 45$ 's second choice was Region 15, Southeast Asia. That region was also not available. Therefore, Marine  $m = 45$  was assigned his 3rd choice, Region 2, Central Asia.

### *c. Limitations*

Because not every Marine spoke a language, the top trading cycle was limited to only the first part of the matching process. This limited the two-sided matching to 15 regions. Because some regional languages were not spoken at all, some regions had no preferences for Marines. Random serial dictatorship was time consuming and took close to four hours per group. Each assignment group contained about 70 Marines. In order to assign an entire company (250 Marines) or the sergeant population (600-700 Marines), the process would have to be computerized. The model assigned the most Marines to their first choice, but unlike Benchmark IP and Optimization with USMC preferences models, there were Marines assigned choices as low as 15, or 17. The further the Marine is on the random list, the more difficult it will be for that Marine to receive a higher preference.

## **E. MATERIALS AND METHODS**

### **1. Data Collection**

The preference data were collected into a spreadsheet by the staff of Delta Company, The Basic School, Quantico, VA, as part of the upcoming assignment process following the RCLF information brief. The data contained the assignment preferences for 223 Marine Officers in Delta Company out of the 251 Marines assigned. The data

contained the officer's name, rank, years on active duty, language knowledge, regional preference, and justification for first choice. The instrument used to collect data from The Basic School is available in Appendix B. Since the listing contained officers' names, each officer was randomly assigned a number to protect the officer's identity while working with the data.

Although the data obtained from The Basic School do not contain every Marine's preference, it does not diminish the effectiveness of the models. The models can be run regardless of the population size. For the purpose of this thesis, the population of Delta Company will be considered  $N=223$ .

## **2. Method**

After the model was developed, the TBS spreadsheet containing Marines' preferences was divided into 3 groups. Platoon 1 and 2 were assigned to Model I Benchmark IP as the primary means for assignment and evaluation. The first group contained 80 Marines and 1360 decision variables. Group 2, consisting of platoons 3 and 4, contained 69 Marines and consisted of 1173 variables and was assigned TTC/SD as the primary assignment model. Group 3, consisting of platoons 5 and 6, contained 74 Marines and 1258 variables, was assigned the Optimization with USMC preferences as the primary assignment model. Each Marine was assigned a number in lieu of his/her name; the numbers representing each Marine were arranged in ascending order within the model to maintain consistency across all models.

The variables in the model for a company size element at The Basic School with 17 regional preferences exceed 4,000 variables. This exceeds Microsoft Excel's basic capabilities to compute the results using the build-in Solver function. This resulted in the upgrade of Microsoft Excel with Frontline Solver Analytic Solver Platform with the Extra Large-Scale LP/QP Solver Engine. The Frontline Solver upgrade allows the model to have unlimited number of variables or constraints. The cost of Frontline Solver and the limited licensing will likely make it cost prohibitive to obtain for the Marine Corps in order to run the optimization model for future assignments.

An open source optimization solver for Excel called OpenSolver ([www.opensolver.org](http://www.opensolver.org)), discovered during subsequent research, is capable of running this large-scale model. According to OpenSolver.org, OpenSolver is “linear and integer optimizer for Microsoft Excel.....an Excel VBA add-in that extends Excel’s built-in Solver with a more powerful Linear Programming solver.” More importantly, the software, as an open source, is available for download to anyone at no cost. Unfortunately, it is not allowed on Navy-Marine Corps Intranet-owned computers due to current Marine Corps Information Technology policy, therefore, making it inaccessible to the Marines who would conduct the assignment process.

We used FrontLine Solver software to solve our large scale problems. The Solver provides a feasible and optimal solution by finding a combination of values for the decision variables that minimize the objective function. Since the model uses mixed-integer programming, the constraints are non-convex. For non-convex problems, Solver uses the Interval Branch and Bound Method to find a solution.

The Interval Branch and Bound Method, according to Frontline Solver, is “an algorithm that will find the globally optimal solution” (p 204). A globally optimal solution “is one where there are no other feasible solutions with better objective function values” (p. 185). In the context of this model, the value of the objective function will always be the same, but there can be different decision variables combinations on how that objective function value can be achieved. That is one of the limitations of the model.

To learn more about the Branch and Bound Method algorithm in Frontline Solver, refer to Appendix H.

Although it is not necessary to explain the full workings of Frontline Solver, the user should understand how the program arrives at a solution. Since the model can be used in other programs, such as the OpenSolver, the assignment solution may differ from Frontline. The different answers do not mean that one program is wrong. This demonstrates that the same equation can be solved by different combinations of the decision variables, while arriving at the same number for the objective function. Both solutions are optimal because they satisfy the requirements of the model.

### **3. Survey Design**

The intent of the survey is to reveal the Marine's preference for assignment—random or based on ranking the Marine's preference from 1-17. Additionally, the survey will ask participants to rank their satisfaction with the random and proposed assignment processes. It will also ask at what point the Marines are indifferent to their assignment and if they think the Marines should have the ability to state their preference. Although the survey could have contained many questions pertaining to the current and proposed assignment process, it was limited to nine questions. A short survey minimized the impact on The Basic School operational environment which had to be taken into consideration in order to encourage participation in the surveys.

To illicit a response from the participants, all but one question is closed-ended. This prevents a non-response bias. Closed-ended questions are easier to tabulate and quantify the responses for analysis. Answers are on a five-point Liker scale, where extremes are equally distant from neutral center. Open-ended questions are evaluated mostly qualitatively, but will be coded for a yes, no, and indifferent response to allow for quantitative analysis. Open-ended questions that do not answer the question will be eliminated from the analysis. There is one open-ended question at the end to allow Marines the opportunity to respond in their own words about their satisfaction with the current assignment process or provide an opinion why Marine preferences should be considered during the assignment process. The open-ended question is limited to one since open-ended questions are more burdensome on respondents and are more difficult to analyze.

The survey is web-based (self-administered), utilizing LimeSurvey. LimeSurvey is a Department of Defense (DoD) approved survey tool that meets DoD safeguarding and privacy requirements. To prevent a coverage error, all members of the population will have equal opportunity to participate in the survey. Since all Marine Lieutenants in Delta Company will receive the brief about survey participation, there will be minimum coverage error.

The Delta Company population size is  $N=223$ . In order to obtain a 95% confidence level and a 5% confidence interval, the sample survey size needs to be 141 Marines. The sample size was calculated using the infinite population with a 95% confidence level, 5% confidence interval, and a  $p$  of 0.5 adjusted for a finite population.

$$\text{Hence: } SS = \frac{1.96^2 * 0.5 * (1 - 0.5)}{0.05^2} = 384 \text{ (infinite population)}$$

$$\text{New } SS = \frac{384}{1 + \left(\frac{384 - 1}{223}\right)} = 141 \text{ (finite population)}$$

Refer to Appendix I for survey questions.

## **IV. RESULTS AND ANALYSIS**

### **A. RESULTS**

Delta Company was divided into three groups to allow for greater data collection since only one company was participating in the research. Each group was assigned regions using all three models to allow for comparison within the group. The results for each group and the entire company are covered in this section. In addition, to obtain the student opinions on the assignment process, a survey was conducted. The results of the survey are also covered in this section.

#### **1. Results for Group 1: Platoons 1 and 2**

Group 1 contained 80 Marines. The most popular region was region 16, Central America & Caribbean Basin, and region 17, South America. The least popular regions were region 2, Central Asia, region 11, Eastern Africa, and region 12, Central Africa. These regions were not listed as anyone's first choice. Region 12 was also not listed as a second choice for any of the 80 Marines. Table 1 depicts the regional popularity for Group 1.

Preference	1. Trans-Caucasus	2. Central Asia	3. Balkans	4. North Africa	5. The Levant	6. Arabian Peninsula and Gulf	7. West South Asia	8. South Asia	9. Western Africa	10. The Sahel	11. Eastern Africa	12. Central Africa	13. Southern Africa	14. Northeast Asia	15. Southeast Asia	16. Central America & Caribbean Basin	17. South America
Quota Available	3	4	3	3	3	11	10	5	4	3	7	3	3	7	5	3	3
1st Choice Ranking	2	0	2	7	7	3	1	3	4	2	0	0	2	8	8	19	12
2nd Choice Ranking	1	3	5	3	2	3	3	2	4	0	10	0	3	6	6	11	18
3rd Choice Ranking	2	1	3	4	5	5	1	6	8	3	1	8	6	2	9	7	9
4th Choice Ranking	1	3	9	8	4	2	3	1	7	6	3	3	6	10	4	5	5
5th Choice Ranking	5	1	5	7	2	2	2	7	2	3	3	9	9	4	7	7	5
6th Choice Ranking	4	2	5	4	7	7	5	3	5	4	9	5	11	4	2	1	2
7th Choice Ranking	5	6	2	12	2	7	1	7	5	4	7	3	8	3	2	3	3
8th Choice Ranking	5	5	6	6	7	3	2	6	9	5	5	4	5	1	4	5	2
9th Choice Ranking	6	0	8	6	1	4	6	4	2	5	6	7	5	7	5	6	2
10th Choice Ranking	6	4	4	4	5	6	3	2	6	4	10	5	4	4	6	0	7
11th Choice Ranking	10	6	5	4	3	4	8	3	3	6	6	4	3	8	4	2	1
12th Choice Ranking	3	10	0	6	4	4	11	6	2	6	4	8	2	4	4	3	3
13th Choice Ranking	2	6	7	3	6	5	4	9	7	5	3	6	6	3	4	3	1
14th Choice Ranking	6	10	3	4	7	7	6	7	7	4	4	4	2	2	5	0	2
15th Choice Ranking	8	5	4	1	6	8	8	3	3	8	5	6	2	6	4	2	1
16th Choice Ranking	4	11	5	1	8	5	7	5	5	11	3	1	2	8	0	3	1
17th Choice Ranking	10	7	7	0	4	5	9	6	1	4	1	7	4	0	6	3	6

Table 1. Regional Popularity: Group 1

Since Regions 2, 11, and 12 were not popular, and regions 16 and 17 exceeded their popularity, at least 49% of Marines in Group 1 will not be able to get their 1st choice. Benchmark IP (Model I) was able to assign 33 or 41% of Marines their first choice. Optimization with USMC preferences (Model II) also assigned 33 or 41% of Marines their first choice. TTC/SD (Model III) assigned 43 or 54% of Marines their first choice. While Models I and II were able to fill 94% and 89% of top four choices respectively, Model III, however, was able to fill only 78% within the top four choices. Marines assigned using Model III were assigned choices as low as 12, 15, and 16. Table 2 depicts the percentage of Marines assigned their preferences by each model.

	Benchmark IP	Opt w/ USMC pref	TTC/SD
1st Choice	41%	41%	54%
2nd Choice	26%	21%	10%
3rd Choice	15%	18%	10%
4th Choice	11%	9%	4%
5th Choice	0%	4%	1%
6th Choice	5%	6%	9%
7th Choice	1%	1%	1%
8th Choice	0%	0%	1%
9th Choice	0%	0%	4%
10th Choice	0%	0%	3%
11th Choice	0%	0%	0%
12th Choice	0%	0%	1%
13th Choice	0%	0%	0%
14th Choice	0%	0%	0%
15th Choice	0%	0%	1%
16th Choice	0%	0%	1%
17th Choice	0%	0%	0%

Table 2. Percentage of Group 1 (80 Marines) Assigned Their Preference

## 2. Results for Group 2: Platoons 3 and 4

Group 2 contained 69 Marines. The most popular regions were region 16, Central America & Caribbean Basin, region 5, The Levant, and region 14, Northeast Asia. The least popular regions were region 2, Central Asia, and region 8, South Asia. These regions were not listed as anyone's first choice. Table 3 depicts the regional popularity for Group 2.

Preference	1. Trans-Caucasus	2. Central Asia	3. Balkans	4. North Africa	5. The Levant	6. Arabian Peninsula and Gulf	7. West South Asia	8. South Asia	9. Western Africa	10. The Sahel	11. Eastern Africa	12. Central Africa	13. Southern Africa	14. Northeast Asia	15. Southeast Asia	16. Central America & Caribbean Basin	17. South America
Quota Available	2	3	2	3	2	11	8	4	3	3	7	2	2	7	4	3	3
1st Choice Ranking	1	0	7	3	9	3	1	0	3	1	1	2	2	9	7	12	8
2nd Choice Ranking	7	1	7	2	6	3	0	3	4	0	3	0	1	3	7	9	13
3rd Choice Ranking	4	4	8	6	2	4	1	1	0	3	4	3	3	6	7	8	5
4th Choice Ranking	2	1	2	3	6	1	8	2	1	1	4	4	5	7	4	5	13
5th Choice Ranking	5	5	3	6	5	4	2	4	4	1	2	2	7	4	3	9	3
6th Choice Ranking	6	1	4	5	4	6	1	5	5	2	4	3	10	1	4	4	4
7th Choice Ranking	5	0	4	4	4	6	5	6	6	3	1	4	7	4	4	2	4
8th Choice Ranking	4	7	6	6	5	4	1	3	3	3	4	3	2	5	3	8	2
9th Choice Ranking	3	5	5	4	2	3	4	6	4	9	8	5	2	1	1	3	4
10th Choice Ranking	7	5	3	3	2	4	5	3	4	6	6	5	6	5	1	3	1
11th Choice Ranking	4	7	4	1	4	6	5	5	5	4	6	6	2	1	6	0	3
12th Choice Ranking	5	5	4	6	6	3	6	2	9	5	4	3	5	3	0	1	2
13th Choice Ranking	1	8	2	5	2	6	3	2	3	11	3	7	6	1	5	2	2
14th Choice Ranking	2	6	3	4	1	3	8	6	5	6	8	3	5	3	3	1	2
15th Choice Ranking	1	8	2	7	6	2	6	6	6	3	4	6	3	3	4	2	0
16th Choice Ranking	4	3	4	2	1	6	5	6	4	10	6	5	3	5	4	0	1
17th Choice Ranking	8	3	1	2	4	5	8	9	3	1	1	8	0	8	6	0	2

Table 3. Regional Popularity: Group 2

Since Regions 2 and 8 were not popular and regions 5, 14, and 16 exceeded their popularity, at least 36% of Marines in Group 2 will not be able to get their 1<sup>st</sup> choice. Benchmark IP was able to assign 30 or 43% of Marines their first choice. Optimization with USMC preferences assigned 33 or 48% of Marines their first choice. TTC/SD assigned 38 or 55% of Marines their first choice. While the two integer programming models were able to fill 96% and 84% of top four choices respectively, TTC/SD, however, was able to fill only 81% within the top four choices. Marines assigned using TTC/SD were assigned choices as low as 14, 15, and 17. Table 4 depicts the percentage of Marines assigned their preferences by each model.

	Benchmark IP	Opt w/ USMC pref	TTC/SD
1st Choice	43%	48%	55%
2nd Choice	17%	7%	6%
3rd Choice	23%	20%	13%
4th Choice	12%	9%	7%
5th Choice	4%	7%	6%
6th Choice	0%	1%	1%
7th Choice	0%	4%	1%
8th Choice	0%	1%	3%
9th Choice	0%	1%	1%
10th Choice	0%	0%	0%
11th Choice	0%	0%	0%
12th Choice	0%	0%	0%
13th Choice	0%	0%	1%
14th Choice	0%	0%	1%
15th Choice	0%	0%	1%
16th Choice	0%	0%	0%
17th Choice	0%	0%	1%

Table 4. Percentage of Group 2 (69 Marines) Assigned Their Preference

### 3. Results for Group 3: Platoons 5 and 6

Group 3 contained 74 Marines. The most popular region was region 16, Central America & Caribbean Basin, and region 3, Balkans. The least popular regions were region 4, North Africa, and region 10, The Sahel. These regions were not listed as anyone's first choice. Region 10 was also not listed as a second choice for any of the 74 Marines. Table 5 depicts the regional popularity for Group 3.

Preference	1. Trans-Caucasus	2. Central Asia	3. Balkans	4. North Africa	5. The Levant	6. Arabian Peninsula and Gulf	7. West South Asia	8. South Asia	9. Western Africa	10. The Sahel	11. Eastern Africa	12. Central Africa	13. Southern Africa	14. Northeast Asia	15. Southeast Asia	16. Central America & Caribbean Basin	17. South America
Quota Available	2	4	2	3	2	11	9	4	4	3	8	2	2	8	4	3	3
1st Choice Ranking	2	1	11	0	5	2	2	2	2	0	1	3	5	8	4	16	10
2nd Choice Ranking	9	1	6	4	3	0	1	2	2	0	4	2	1	3	6	15	15
3rd Choice Ranking	6	3	9	5	5	3	0	2	2	2	2	2	4	7	9	6	7
4th Choice Ranking	7	3	8	5	6	4	5	3	3	2	4	0	5	3	2	4	10
5th Choice Ranking	6	2	5	4	7	2	3	6	5	4	5	4	3	6	3	4	5
6th Choice Ranking	7	3	3	8	3	8	1	3	5	3	5	2	4	2	6	6	5
7th Choice Ranking	7	4	2	5	5	7	1	7	3	1	2	8	8	4	7	1	2
8th Choice Ranking	3	7	3	9	4	3	2	6	1	6	4	1	7	6	7	4	1
9th Choice Ranking	2	5	4	8	7	4	5	6	6	4	2	4	5	5	2	4	1
10th Choice Ranking	3	3	5	1	4	7	12	6	3	5	5	5	4	5	4	0	2
11th Choice Ranking	5	8	4	3	0	8	7	6	6	5	6	3	1	5	5	2	0
12th Choice Ranking	4	9	1	4	5	2	5	8	5	6	11	5	2	1	3	0	3
13th Choice Ranking	1	7	4	5	5	2	6	7	10	7	4	6	3	3	3	1	0
14th Choice Ranking	4	6	1	6	0	5	2	1	10	11	5	8	5	6	3	0	1
15th Choice Ranking	1	2	2	5	1	4	11	6	5	6	8	3	10	2	3	2	3
16th Choice Ranking	2	2	3	2	6	7	6	2	5	9	6	4	3	4	4	5	4
17th Choice Ranking	5	8	3	0	8	6	5	1	1	3	0	14	4	4	3	4	5

Table 5. Regional Popularity: Group 3

Since Regions 4 and 10 were not popular and regions 3 and 16 exceeded their popularity, at least 38% of Marines in Group 3 will not be able to get their 1st choice. Benchmark IP was able to assign 28 or 38% of Marines their first choice. Optimization with USMC preferences assigned 29 or 39% of Marines their first choice. TTC/SD assigned 30 or 41% of Marines their first choice. While the integer programming models were able to fill 89% and 86% of top four choices respectively, TTC/SD, however, was able to fill only 68% within the top four choices. Marines assigned regions using TTC/SD were awarded choices as low as 12 and 16. Table 6 depicts the percentage of Marines assigned their preferences by each model.

	Benchmark IP	Opt w/ USMC pref	TTC/SD
1st Choice	38%	39%	41%
2nd Choice	15%	12%	4%
3rd Choice	20%	16%	9%
4th Choice	16%	19%	14%
5th Choice	5%	3%	5%
6th Choice	4%	7%	8%
7th Choice	1%	4%	7%
8th Choice	0%	0%	3%
9th Choice	0%	0%	3%
10th Choice	0%	0%	1%
11th Choice	0%	0%	3%
12th Choice	0%	0%	1%
13th Choice	0%	0%	0%
14th Choice	0%	0%	0%
15th Choice	0%	0%	0%
16th Choice	0%	0%	1%
17th Choice	0%	0%	0%

Table 6. Percentage of Group 3 (74 Marines) Assigned Their Preference

#### 4. Delta Company Results

Delta Company provided 223 preference inputs from a total of 251 Marines in the company. The most popular regions were region 16, Central America & Caribbean Basin, region 17, South America, and region 14, Northeast Asia. The least popular regions were region 2, Central Asia, region 10, The Sahel, and region 11, Eastern Africa. Table 7 depicts the regional popularity for the company.

Preference	1. Trans-Caucasus	2. Central Asia	3. Balkans	4. North Africa	5. The Levant	6. Arabian Peninsula and Gulf	7. West South Asia	8. South Asia	9. Western Africa	10. The Sahel	11. Eastern Africa	12. Central Africa	13. Southern Africa	14. Northeast Asia	15. Southeast Asia	16. Central America & Caribbean Basin	17. South America
Quota Available	7	11	7	9	7	33	27	13	11	9	22	7	7	22	13	9	9
1st Choice Ranking	5	1	20	10	21	8	4	5	9	3	2	5	9	25	19	47	30
2nd Choice Ranking	17	5	18	9	11	6	4	7	10	0	17	2	5	12	19	35	46
3rd Choice Ranking	12	8	20	15	12	12	2	9	10	8	7	13	13	15	25	21	21
4th Choice Ranking	10	7	19	16	16	7	16	6	11	9	11	7	16	20	10	14	28
5th Choice Ranking	16	8	13	17	14	8	7	17	11	8	10	15	19	14	13	20	13
6th Choice Ranking	17	6	12	17	14	21	7	11	15	9	18	10	25	7	12	11	11
7th Choice Ranking	17	10	8	21	11	20	7	20	14	8	10	15	23	11	13	6	9
8th Choice Ranking	12	19	15	21	16	10	5	15	13	14	13	8	14	12	14	17	5
9th Choice Ranking	11	10	17	18	10	11	15	16	12	18	16	16	12	13	8	13	7
10th Choice Ranking	16	12	12	8	11	17	20	11	13	15	21	15	14	14	11	3	10
11th Choice Ranking	19	21	13	8	7	18	20	14	14	15	18	13	6	14	15	4	4
12th Choice Ranking	12	24	5	16	15	9	22	16	16	17	19	16	9	8	7	4	8
13th Choice Ranking	4	21	13	13	13	13	13	18	20	23	10	19	15	7	12	6	3
14th Choice Ranking	12	22	7	14	8	15	16	14	22	21	17	15	12	11	11	1	5
15th Choice Ranking	10	15	8	13	13	14	25	15	14	17	17	15	15	11	11	6	4
16th Choice Ranking	10	16	12	5	15	18	18	13	14	30	15	10	8	17	8	8	6
17th Choice Ranking	23	18	11	2	16	16	22	16	5	8	2	29	8	12	15	7	13

Table 7. Regional Popularity: Delta Company

Since Regions 2, 10, and 11 were the least popular, and regions 14, 16, and 17 exceeded their popularity, at least 44% of Marines in Delta Company will not be able to get their 1st choice. Benchmark IP model was able to assign 97 or 43% of Marines their first choice. Optimization with USMC preference assigned 102 or 46% of Marines their first choice. TTC/SD assigned 102 or 46% of Marines their first choice. While the integer programming models were able to fill 93% and 88% of top four choices, respectively, TTC/SD, however, was able to fill only 73% within the top four choices. Marines assigned using TTC/SD were assigned choices as low as 15, 16, and 17. Table 8 depicts the percentage of Marines assigned their preferences by each model.

	Benchmark IP	Opt w/ USMC pref	TTC/SD
1st Choice	43%	46%	46%
2nd Choice	20%	15%	9%
3rd Choice	17%	16%	9%
4th Choice	12%	11%	9%
5th Choice	4%	5%	4%
6th Choice	3%	5%	6%
7th Choice	0%	1%	4%
8th Choice	0%	0%	1%
9th Choice	0%	0%	3%
10th Choice	0%	0%	1%
11th Choice	0%	0%	2%
12th Choice	0%	0%	0%
13th Choice	0%	0%	0%
14th Choice	0%	0%	0%
15th Choice	0%	0%	1%
16th Choice	0%	0%	1%
17th Choice	0%	0%	1%

Table 8. Percentage of Delta Company (223 Marines) Assigned Their Preference

## 5. Survey Results

The Marines in Delta Company were asked several questions to assess their satisfaction with the proposed assignment process and to gather their opinion on whether Marines should be given the chance to state their preferences during an assignment

process. The survey was available to all 223 Marines whose preference data were collected. The survey response rate was 83% with 185 Marines taking the survey. Total number of responses to the survey was 191. There were duplicate entries and answers from Marines who were assigned by The Basic School, but not as part of this thesis research. As a result, six entries were removed from the analysis. The number of valid survey responses met the goal for a 95% confidence level and a 5% confidence interval.

The results of the survey show that Marines would prefer to state their preferences during the assignment process. Of the 185 Marines, 182 or 98% responded that the Marine Corps should take Marines' preferences into considerations during the assignment process. Of the 2% of Marines who responded "no," only two Marines answered the open-ended question. Both Marines indicated that their regional preferences were based on family background and language knowledge, but neither was awarded their first choice. The Marines were not awarded their first choice because there were other, equally qualified Marines for those regions who were assigned and, therefore, there were no additional quotas available to any, equally qualified Marine.

The Marines were given the option to elaborate on their position of why the Marine Corps should take preferences into consideration. The Marines that responded to the open-ended question agreed that giving Marines a choice will encourage Marines to consider the RCLF program as more than just a check in the box for promotion. The officers believe that a Marine is more likely to actively participate in the RCLF studies if he/she is given a region based on his/her preferences.

The Marines were assigned a region using one of the three models and asked to assess their satisfaction with their assignment. In 72% of the assignments, or in 134 cases, the Marines were either very satisfied or satisfied with their regional placement. When the Marines were told they were randomly assigned a region, in this case, region 6, the Arabian Peninsula & Gulf, the very satisfied and satisfied ranking dropped to 36% or 67 Marines. During the random assignment, 79 Marines or 42% were indifferent to the assigned region as opposed to 33 Marines or 18% previously. Figure 3 represents the comparisons among satisfaction in assignments with preference consideration and random assignment.

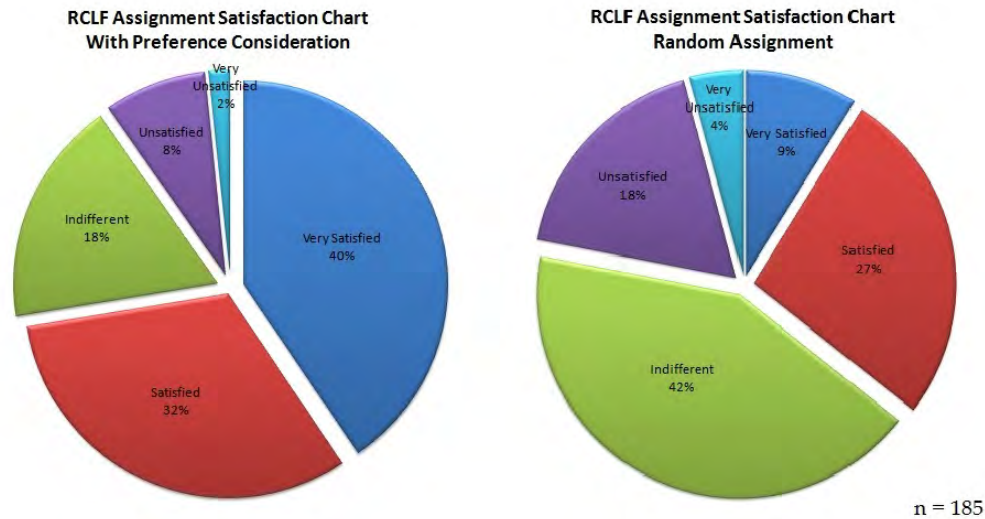


Figure 3. Assignment Satisfaction

The Marines were asked, in a close-ended question, after what preference they would be indifferent to their assignment. The choice brackets were determined to best represent the overall ability of each model to assign Marines to their preferences. The following choices were available to the Marines: indifference after 4th, 7th, 10th, or 14th choice. The majority of the Marines, 133 or 72%, indicated that they would be indifferent after their 4th choice.

Marines were asked to rate their satisfaction with the assignment. Of the 65 Marines from Group 1 that responded, 74% were very satisfied or satisfied with the Benchmark IP assignment process. Only seven Marines or 11% were unsatisfied or very unsatisfied with Benchmark IP performance. Optimization with USMC preferences had the greatest assignment satisfaction within the group. Of the 57 Marines from Group3 that responded, 77% were very satisfied and satisfied with the assignment. Only four or 7% of Marines showed dissatisfaction with the assignments. TTC/SD had the least satisfied Marines. Of the 63 Marines in Group 2 that responded to the survey, 42 Marines or 67% were very satisfied or satisfied with the assignments. Seven or 12% of the Marines were unsatisfied or very unsatisfied. See Table 9 for comparison.

Assignment Satisfaction by Model			
	Benchmark IP	Opt w/ USMC pref	TTC/SD
Very Satisfied	40%	44%	38%
Satisfied	34%	33%	29%
Indifferent	15%	16%	22%
Unsatisfied	8%	7%	10%
Very Unsatisfied	3%	0%	2%

Table 9. Assignment Satisfaction by Model

## B. ANALYSIS

Random assignment is not efficient because better assignment choices can be made and, therefore, not recommended for The Basic School. Random assignment is also not Pareto efficient because Marines can be matched to a different region without making someone else less happy. The survey shows that Marines would also prefer to have a preference over assignments than be randomly assigned. In addition, having a general interest in the assigned region is more likely to entice the Marines to be more enthusiastic about the RCLF program.

Since the popularity of the regions is very non-uniform, it makes future model performance determination impossible. One cannot say with certainty that every time the model is run, 40% of Marines will receive their first choice. The performance of a model is tied to regional popularity. If one or several regions enjoy high level of popularity, such as regions 16 and 17 in this case, the model performance results will be different than if popularity is uniformly distributed among the regions.

In addition to comparing the performance of each model based on percentage of Marines assigned a particular preference, the models were compared using mean and standard deviation to assess their performance. In the case of Delta Company, the model with the best mean and standard deviation was Benchmark IP. TTC/SD had the greatest variation in filling preferences. The performance of the models for Delta Company as a whole mirrored the same performance when the company was assigned into three different groups. Model I had the lowest mean and standard deviation while TTC/SD had the highest mean and standard deviation in all cases. Standard error calculations were not

used since the mean and standard deviation apply to the entire population as opposed to a sample. Table 10 reflects the performance of each model.

Delta Company	Benchmark IP	Opt w/ USMC pref	TTC/SD
Mean	2.23	2.59	3.55
Standard Deviation	1.43	1.51	3.55
Group 1 (Platoon 1+2)			
Mean	2.23	2.59	3.09
Standard Deviation	1.44	1.42	3.34
Group 2 (Platoon 3+4)			
Mean	2.16	2.81	3.04
Standard Deviation	1.22	1.83	3.51
Group 3 (Platoon 5+6)			
Mean	2.54	2.86	3.81
Standard Deviation	1.55	1.65	3.25

Table 10. Model Performance Based on Mean and Standard Deviation

The survey results indicate that Marines would prefer to rank their preferences during the RCLF assignment process and would be indifferent after their 4<sup>th</sup> choice. The models were, therefore, compared on their ability to assign the most Marines within their top four choices, standard deviation, ability to provide Pareto efficient, strategy proof, and transparent assignments. Since the assignments can be done on a platoon level (about 35 Marines), company (about 250 Marines), or entire population of newly promoted Marine Sergeants (about 600-700 Marines), the ability to scale the model was taken into consideration during the evaluation.

To calculate which model is best for the assignment process, each rating was assigned a numerical value. The values were then added and the model with the highest score was deemed as best in meeting all the evaluation criteria. Each yes or no answer was assigned a value of “1” for “yes” and value of “0” for “no”. In order to rate the performance of each model, values “1, 2, and 3” were used. Value “3” means the model has the best performance or the highest ranking, while value “1” means the model was rated last in performance.

Based on the survey results, Optimization with USMC preferences received the highest score for officer satisfaction. When comparing models based on assignment within the top four choices, Benchmark IP scored the highest. Benchmark IP had the lowest standard deviation and the lowest mean, therefore earning a score of “3” for performance.

All three models are considered to be Pareto efficient because there cannot be better matches made without putting someone else in a worse position. Being Pareto efficient is important in the assignment process because as many Marines as possible should receive their highest choice. To define something strategy proof, means that the system cannot be gamed to receive a better choice by not revealing true preferences. Only TTC/SD is considered strategy proof among the three. It is unlikely, however, that Marines will be able to strategize the optimization models because they are complex. If one were to understand the algorithm behind the assignment process, it would be possible to game the system.

Because everyone knows how the assignment process is done, transparency is also only applicable to TTC/SD. The top trading cycle is based on priorities and trading while the random assignment is random. Thus, there is no question on how the assignments were accomplished. The two optimization models are based on an equation. It is not clear, even when one understands the algorithm behind the assignment process, why Marine 1 receives choice 2 and Marine 3 receives choice 3 and vice versa. The equation would be satisfied the same, regardless if Marine 1 receives choice 2 or 3 if Marine 3 receives choice 3 or 2. What is not transparent is which Marine receives the higher choice.

Last, each model was evaluated on the economy of scale or how difficult it would be to apply the model to larger populations. In case of the integer programming models, it can be easily applied to any size population, ranging from platoon, to company, to entire population of sergeants. TTC/SD can still be applied to any size population, but the larger the population, the longer it takes to assign Marines unless the process becomes automated.

Once the scores were compiled, Benchmark IP received the highest ranking. Optimization with USMC preferences was in close second while TTC/SD received the lowest score. The most desirable model for the assignment process as it exists today is Benchmark IP. It has the ability to give the most Marines an assignment within their top four choices. The scoring can be viewed in Table 11.

Delta Company	Benchmark IP	Opt w/ USMC pref	TTC/SD
Officer satisfaction with each Model	2	3	1
Ability to assign most Marines within top 4 choices	3	2	1
Standard deviation	3	2	1
Pareto efficiency	1	1	1
Strategy proofness	0	0	1
Transparency	0	0	1
Economy of Scale	1	1	0
Score	10	9	6

Table 11. Model Scoring

### C. SUMMARY

The results for each model indicate that each one can be implemented to meet the assignment needs for both The Basic School officer population and the newly promoted sergeant population that gets assigned on a monthly basis. The model with the best performance and therefore the one that should be adapted, however, is the Benchmark IP model which is using integer programming and optimization to assign Marines. At the present time, the RCLF office does not have a preference for which Marine is assigned to a region, further making Benchmark IP the best suited. If the RCLF office changes the assignment process and does take language into consideration, then Optimization with USMC preferences will be a suitable replacement. Because the regional preferences are not uniformly distributed, the success rate for future assignments cannot be guaranteed for any model. Each company or sergeant population is likely to have different regional preferences, making the assignment distribution unique. In all cases, Benchmark IP will optimally assign Marines based on the ranking and quotas available regardless the distribution. Marines will still receive their highest choice possible given the constraints.

In summary, Benchmark IP should become the assignment tool instead of the random or manual assignment conducted by The Basic School or the RCLF office.

## **V. CONCLUSION AND RECOMMENDATIONS**

### **A. SUMMARY**

The research results support the recommendation that RCLF office and The Basic School should not continue to randomly assign Marines because the process is not efficient. RCLF office should formalize the process and use an assignment process that takes preferences into consideration. All models showed improvements in assignment satisfaction over random assignment. Given the continual nature of the RCLF assignment, the program will require an improvement to the assignment process so that Marines treat the program as more than a check in the box.

The purpose of this research was to evaluate the three different models that are widely applied in similar matching situations and to make a recommendation as to which model is best suited. Model I Benchmark IP had the highest success rate in assigning Marines a preference within one of their top four choices. Utilizing Model I Benchmark IP, the assignment process can be applied both to The Basic School as well as to the sergeant population. The model can be scaled to any size population utilizing either the Frontline Solver or the OpenSolver ad-on software for Microsoft Excel.

Although the preference data collection is time consuming, once the data are inputted into the model, the model takes less than a minute to produce the assignment. If the model is set up and the data collected in a manner that can make it plug and play, the model will eliminate the labor hours currently needed to manually match Marines to their preferences.

If the assignment process were to change and the Marine Corps wanted to match students based on language knowledge or existing regional knowledge, the model can be modified with additional constraints or variables.

### **B. RECOMMENDATIONS FOR FURTHER RESEARCH**

The research focused on recommending the best assignment model to distribute the available quotas while giving most Marines their top preference. The research did not

make suggestions about how to implement the model for future assignments. Follow up research on preference collection, software acquisition, or open source use software approval would help the RCLF program in formalizing the assignment process.

Additional research can be conducted to determine if the model is fair and strategy proof. It would also be prudent to run simulations of the model on how well the model performs given different preference distributions.

## APPENDIX A. RCLF REGIONS AND LANGUAGES

REGIONS	REQUIREMENT	COUNTRIES	LANGUAGES (Nine Core)	LANGUAGES (Six Add)
1. Trans-Caucasus	3%	Turkey, Georgia, Armenia, Azerbaijan	Russian	Turkish
2. Central Asia	5%	Afghanistan, Kazakhstan, Mongolia, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan	Russian	
3. The Balkans	3%	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Kosovo, Macedonia, Montenegro, Romania, Serbia, Slovenia, Turkey	Russian	
4. North Africa	4%	Algeria, Egypt, Libya, Morocco, South Sudan, Sudan, Tunisia	Arabic, French	
5. The Levant	3%	Turkey, Syria, Lebanon, Israel, Jordan	Arabic	
6. Arabian Peninsula & Gulf	15%	Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen	Arabic, Farsi	
7. West South Asia	12%	Afghanistan, Iran, Pakistan	Farsi, Urdu	Pashto, Dari
8. South Asia	6%	Bangladesh, India, Nepal, Pakistan, Sri Lanka	Urdu	
9. Western Africa	5%	Benin, Burkina Faso, Cape Verde, Cote D'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Mauritania, Mali, Niger, Nigeria, Principe, São Tome, Senegal, Sierra Leone, The Gambia, Togo	French	
10. The Sahel	4%	Mali, Niger, Nigeria, Libya, Chad, South Sudan, Sudan	French	
11. Eastern Africa	10%	Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Tanzania, Uganda	Arabic	
12. Central Africa	3%	Burundi, Cameroon, Central African Republic, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Republic of the Congo, Rwanda	French	Swahili
13. Southern Africa	3%	Angola, Botswana, Comoros, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Zimbabwe, Zambia	Portuguese, French	
14. Northeast Asia	10%	Mongolia, China, Japan, North Korea, South Korea, Taiwan	Chinese (Mandarin), Korean	
15. Southeast Asia	6%	Brunei Darussalam, Burma, Cambodia, East Timor, Indonesia, Laos, Malaysia, Palau, Papua New Guinea, Philippines, Singapore, Solomon Islands, Thailand, Vietnam	TBD	Tagalog, Thai
16. Central America & Caribbean Basin	4%	Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guadeloupe, Guatemala, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, St. Barthelemy, St. Kitts & Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos Islands, Virgin Islands	Spanish, French	
17. South America	4%	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela	Spanish, Portuguese	

**Source:** Marine Requirements Oversight Council (MROC) Decision Memorandum 38-2012. (2012, May 24). Department of the Navy, Headquarters United States Marine Corps [Memorandum]. Washington, DC: Deputy Commandant, Combat Development and Integration., p. 22–23

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## **APPENDIX B. DATA COLLECTED FROM DELTA COMPANY, THE BASIC SCHOOL**

Last Name

First Name

Platoon

Rank

Years on Active Duty

Undergraduate Degree

Language Fluent in (other than English)

Native Speaker?

DLPT Score (if available)

Language Fluent in (other than English)

Native Speaker?

Language Familiar with (other than English)

Language Familiar with (other than English)

Regional Ranking 1-17

First Choice Justification

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## APPENDIX C. BENCHMARK IP SET UP IN EXCEL

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## APPENDIX D. BENCHMARK IP SET UP IN EXCEL WITH FRONTLINE SOLVER

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2	Section 1	<b>Marine Preferences</b>	<b>80</b>	<i>m1</i>	<i>m2</i>	<i>m3</i>	<i>m4</i>	<i>m5</i>	<i>m6</i>	<i>m7</i>	<i>m8</i>	<i>m9</i>	<i>m10</i>	<i>m11</i>	<i>m12</i>	<i>m13</i>	<i>m14</i>
3		1. Trans-Caucasus	3%	11	7	6	17	10	15	11	9	9	8	8	10	17	17
4		2. Central Asia	5%	7	8	13	13	11	2	4	8	16	6	7	11	12	15
5		3. Balkans	3%	9	9	11	15	13	17	17	3	17	4	13	4	16	16
6		4. North Africa	4%	1	10	7	8	12	11	1	5	4	12	2	5	6	5
7		5. The Levant	3%	8	11	15	16	14	8	15	11	3	10	14	13	15	1
8		6. Arabian Peninsula and Gulf	15%	6	12	10	14	1	3	3	10	13	9	17	7	14	6
9		7. West South Asia	12%	5	4	14	12	15	1	2	12	15	11	12	17	11	3
10		8. South Asia	6%	14	3	5	11	7	16	14	13	14	16	4	16	1	9
11		9. Western Africa	5%	10	6	8	4	8	12	8	14	8	13	3	6	10	10
12		10. The Sahel	4%	3	13	9	3	16	14	16	17	12	17	16	12	7	11
13		11. Eastern Africa	10%	2	14	12	6	4	10	6	7	7	14	9	8	9	7
14		12. Central Africa	3%	12	15	3	7	6	13	5	15	6	15	6	9	13	13
15		13. Southern Africa	3%	13	5	17	5	9	9	7	6	5	7	5	3	8	12
16		14. Northeast Asia	10%	4	16	16	9	2	4	13	16	11	1	15	15	5	4
17		15. Southeast Asia	6%	15	17	4	10	5	7	12	4	10	2	1	14	4	14
18		16. Central America & Caribbean Basin	4%	16	1	1	2	3	5	9	2	1	5	11	2	2	8
19		17. South America	4%	17	2	2	1	17	6	10	1	2	3	10	1	3	2

		<i>m1</i>	<i>m2</i>	<i>m3</i>	<i>m4</i>	<i>m5</i>	<i>m6</i>	<i>m7</i>	<i>m8</i>	<i>m9</i>	<i>m10</i>	<i>m11</i>	<i>m12</i>	<i>m13</i>	<i>m14</i>	
22	Section 2	<b>Decision variables (Binary)</b>														
23		1. Trans-Caucasus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24		2. Central Asia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25		3. The Balkans	0	0	0	0	0	0	0	1	0	0	0	0	0	0
26		4. North Africa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27		5. The Levant	0	0	0	0	0	0	0	0	1	0	0	0	0	0
28		6. Arabian Peninsula and Gulf	0	0	0	0	1	0	0	0	0	0	0	0	0	0
29		7. West South Asia	0	1	0	0	0	1	1	0	0	0	0	0	0	1
30		8. South Asia	0	0	0	0	0	0	0	0	0	0	0	0	1	0
31		9. Western Africa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32		10. The Sahel	0	0	0	1	0	0	0	0	0	0	0	0	0	0
33		11. Eastern Africa	1	0	0	0	0	0	0	0	0	0	0	0	0	0
34		12. Central Africa	0	0	1	0	0	0	0	0	0	0	0	0	0	0
35		13. Southern Africa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36		14. Northeast Asia	0	0	0	0	0	0	0	0	0	1	0	0	0	0
37		15. Southeast Asia	0	0	0	0	0	0	0	0	0	0	1	0	0	0
38		16. Central America & Caribbean	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39		17. South America	0	0	0	0	0	0	0	0	0	0	0	1	0	0

		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
41	Section 3	<b>Marine must be uniquely assigned to 1 region</b>														
42																
43	Section 4	<b>Min Function (Sum of preferences awarded)</b>	2	4	3	3	1	1	2	3	3	1	1	1	1	3
44																

SUMFCE		CONSTRAINTS
3	=	3
4	=	4
3	=	3
3	=	3
3	=	3
3	=	3
11	=	11
10	=	10
5	=	5
4	=	4
3	=	3
7	=	7
3	=	3
3	=	3
7	=	7
5	=	5
3	=	3
3	=	3

80
178

model scaled

Solver Options and Model Specifications

Model Platform Engine Output

**Optimization**

**Objective**

\$C\$43 (Min)

**Variables**

Normal

\$D\$23:\$CE\$39

Recourse

**Constraints**

Normal

\$C\$23:\$C\$39 = \$C\$23:\$C\$39

\$D\$41:\$C\$41 = 1

Chance

Recourse

Round

111

**Model Diagnosis**

Model Type: Unknown

**Variables - Functions - Dependencies**

	Vars	Fns	Dpns
All	1360	98	N/A
Smooth	N/A	N/A	N/A
Linear	N/A	N/A	N/A
Recourse	0	N/A	N/A

**Model Type**

If Unknown, press the 'Analyze without Solving' button to diagnose the model.

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# APPENDIX E. OPTIMIZATION WITH USMC PREFERENCES SET UP IN EXCEL

Section 1	Marine preferences	74	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1. Truce-Caucasus	3%	17	1	14	2	7	4	6	17	2	12	11	4	8	3	
2. Central Asia	1%	11	8	12	16	11	6	5	3	7	7	4	8	7	13	
3. Balkan	3%	16	2	13	1	15	3	1	11	1	9	10	7	4	11	
4. North Africa	4%	5	6	9	5	3	8	12	16	13	6	7	3	12	8	
5. The Levant	3%	5	6	16	4	9	1	13	15	5	2	9	13	16	1	
6. Arabian Peninsula and Gulf	10%	12	11	15	3	9	7	4	6	11	3	13	16	17	7	
7. West South Asia	12%	15	15	17	12	10	11	4	9	2	5	9	13	15		
8. South Asia	8%	3	7	10	9	6	12	14	5	8	4	2	10	11	12	
9. Western Africa	1%	10	3	6	15	13	13	15	14	14	16	14	2	6	14	
10. The Sahel	4%	4	13	11	12	5	14	16	13	16	10	8	14	15	16	
11. Eastern Africa	10%	9	12	9	14	12	16	10	12	12	11	12	5	9	8	
12. Central Africa	3%	7	15	7	17	2	16	9	10	17	12	16	1	13	12	
13. Southern Africa	3%	6	10	4	10	14	17	8	9	15	14	17	6	14	2	
14. Northeast Asia	10%	14	14	1	11	17	9	17	8	10	8	5	11	3	5	
15. Southeast Asia	6%	13	9	2	8	16	11	7	7	6	1	1	12	5	4	
16. Central America & Caribbean Basin	4%	1	17	8	6	1	2	3	2	4	17	8	17	1	9	
17. South America	4%	2	4	3	7	4	6	2	1	3	15	15	16	2	13	

Section 2	Language 1 - Fluency	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Chinese	N/A	N/A	N/A
Language 2 - Fluency	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Language 3 - Familiar	Spanish	Russian	N/A	Arabic	Spanish	French	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Spanish	Indonesian	N/A	Spanish
Language 4 - Familiar	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Section 3	USMC Language preferences	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1. Truce-Caucasus		1													
2. Central Asia			1												
3. Balkan				1											
4. North Africa					1										
5. The Levant						1									
6. Arabian Peninsula and Gulf							1								
7. West South Asia								1							
8. South Asia									1						
9. Western Africa										1					
10. The Sahel											1				
11. Eastern Africa												1			
12. Central Africa													1		
13. Southern Africa														1	
14. Northeast Asia															1
15. Southeast Asia															
16. Central America & Caribbean Basin															
17. South America															

Section 4	First choice USMC = First choice - m	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1. Truce-Caucasus		1													
2. Central Asia			1												
3. Balkan				1											
4. North Africa					1										
5. The Levant						1									
6. Arabian Peninsula and Gulf							1								
7. West South Asia								1							
8. South Asia									1						
9. Western Africa										1					
10. The Sahel											1				
11. Eastern Africa												1			
12. Central Africa													1		
13. Southern Africa														1	
14. Northeast Asia															1
15. Southeast Asia															
16. Central America & Caribbean Basin															
17. South America															

SUMFCE	CONSTRAINTS	MAX MATCHES
1	0.0	2
2	0.0	4
3	0.0	2
4	0.0	3
5	0.0	2
6	0.0	1
7	0.0	3
8	0.0	4
9	0.0	4
10	0.0	3
11	0.0	4
12	0.0	3
13	0.0	2
14	0.0	2
15	0.0	3
16	0.0	3
17	0.0	3

Section 5	Decision variables (Binary)	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1. Truce-Caucasus		0	1	0	0	0	0	0	0	0	0	0	0	0	0
2. Central Asia		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Balkan		0	0	0	0	0	0	0	0	1	0	0	0	0	0
4. North Africa		0	0	0	0	0	1	0	0	0	0	0	0	0	0
5. The Levant		0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Arabian Peninsula and Gulf		0	0	0	1	0	1	1	0	0	1	0	0	0	1
7. West South Asia		0	0	0	0	0	0	0	1	0	0	0	0	0	0
8. South Asia		0	0	0	0	0	0	0	0	0	0	1	0	0	0
9. Western Africa		0	0	0	0	0	0	0	0	0	0	0	1	0	0
10. The Sahel		1	0	0	0	0	0	0	0	0	0	0	0	0	0
11. Eastern Africa		0	0	0	0	0	0	0	0	0	0	0	0	0	0
12. Central Africa		0	0	0	0	0	0	0	0	0	0	0	0	0	0
13. Southern Africa		0	0	0	0	0	0	0	0	0	0	0	0	0	0
14. Northeast Asia		0	0	1	0	0	0	0	0	0	0	0	0	1	0
15. Southeast Asia		0	0	0	0	0	0	0	0	0	0	0	0	0	0
16. Central America & Caribbean Basin		0	0	0	0	0	0	0	0	0	0	0	0	0	0
17. South America		0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUMFCE	CONSTRAINTS
2	2
4	4
2	2
3	3
2	2
11	11
9	9
4	4
4	4
3	3
6	6
2	2
2	2
6	6
3	3
3	3

Section 6	Marine must be uniquely assigned to 1 region	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Section 7	USMC = Marine match (1 prs, 0 no)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Section 8	Preferences awarded	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Section 9	Min function (Sum of preferences awarded)	4	0	0	0	0	0	0	0	0	0	0	0	0	0

SUMFCE	CONSTRAINTS
14	14
12	12

Model scaled

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## APPENDIX F. OPTIMIZATION WITH USMC PREFERENCES SET UP IN EXCEL WITH FRONTLINE SOLVER

System	Maxim preference	74	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1. Trans-Congo	2/2	11	4	4	17	2	12	11	4	8	3	3				
2. Central-Africa	5/5	11	6	5	3	7	7	4	8	7	13					
3. Balkan	2/2	15	3	1	11	1	9	10	7	4	11					
4. North-Africa	4/5	7	1	12	16	13	4	7	2	12	1					
5. The Levant	2/2	8	1	10	15	9	2	9	10	16	1					
6. Arabian Peninsula and Gulf	15/5	9	7	4	4	11	3	13	16	17	7					
7. West South-Africa	6/5	9	1	10	16	13	4	7	2	12	1					
8. South-Africa	4/5	6	12	14	5	0	4	2	10	11	12					
9. Western-Africa	5/5	13	13	16	14	14	16	14	2	13	14					
10. The Sahel	6/5	5	14	16	13	16	10	4	14	15	16					
11. Eastern-Africa	8/5	12	16	10	12	12	11	12	5	9	6					
12. Central-Africa	2/2	2	16	9	10	17	13	16	1	10	17					
13. Southern-Africa	3/5	14	17	8	9	10	14	17	6	14	2					
14. North-West-Africa	8/5	17	9	17	8	10	6	3	11	3	5					
15. South-West-Africa	4/5	16	11	7	7	4	1	1	12	5	4					
16. Central America & Caribbean Basin	4/5	11	2	3	1	1	1	1	1	1	9					
17. South America	4/5	4	5	2	1	3	15	15	16	2	10					

System	Language 1 - Fluent	N/A	N/A	N/A	N/A	N/A	N/A	Chinese	N/A	N/A	N/A	N/A
Language 2 - Fluent	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Language 3 - Familiar	Spanish	French	N/A	N/A	Spanish	Indonesian	N/A	N/A	N/A	Spanish	Spanish	
Language 4 - Familiar	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

System	USMC Language preference	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1. Trans-Congo															
2. Central-Africa															
3. Balkan															
4. North-Africa			1												
5. The Levant															
6. Arabian Peninsula and Gulf															
7. West South-Africa															
8. South-Africa		1													
9. Western-Africa			1												
10. The Sahel															
11. Eastern-Africa															
12. Central-Africa				1											
13. Southern-Africa				1											
14. North-West-Africa								1							
15. South-West-Africa															
16. Central America & Caribbean Basin		1	1								1				
17. South America						1					1				

System	First choice USMC - First choice m	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10
--------	------------------------------------	----	----	----	----	----	----	----	----	----	-----

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## APPENDIX G. TTC/SD SET UP

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## APPENDIX H. THE BRANCH AND BOUND METHOD

According to the Frontline Solver User Guide, V. 12.5:

The algorithm processes a list of “boxes” that consist of bounded intervals for each decision variable, starting with a single box determined by the bounds that you specify. On each iteration, it seeks lower and upper bounds for the objective and the constraints in a given box that will allow it to discard all or a portion of the box (narrowing the intervals for some of the variables), by proving that the box can contain no feasible solutions, or that it can contain no objective function values better than a known best bound on the globally optimal objective. Boxes that cannot be discarded are subdivided into smaller boxes, and the process is repeated. Eventually, the boxes that remain each enclose a locally optimal solution, and the best of these is chosen as the globally optimal solution (p. 204).

When applied to integer programming, such as this model, the Branch and Bound Method

... begins by finding the optimal solution to the ‘relaxation’ of the integer problem, ignoring the integer constraints. If it happens that in this solution, the decision variables with integer constraints already have integer values, then no further work is required. If one or more integer variables have non-integral solutions, the Branch & Bound method chooses one such variable and ‘branches,’ creating two new subproblems where the value of the variable is more tightly constrained. Hence the Branch & Bound method may solve many subproblems .... the ‘bounding’ part of the Branch & Bound method is designed to eliminate sets of subproblems that do not need to be explored because the resulting solutions cannot be better than the solutions already obtained. p. 209).

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## APPENDIX I: SURVEY QUESTIONS

### RCLF Assignment Survey

**1 Statement of Consent.** I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.\*

Please choose **only one** of the following:

- ☐ Yes      ☐ No

### Demographics

#### 2 Name\*

Please write your answer(s) here:

- First Name \_\_\_\_\_ Last Name \_\_\_\_\_

### RCLF Assignment

#### 3 What is your RCLF assignment?\*

Please choose **only one** of the following:

- ☐ Trans-Caucasus
- ☐ Central Asia
- ☐ The Balkans
- ☐ North Africa
- ☐ The Levant
- ☐ Arabian Peninsula and Gulf
- ☐ West South Asia
- ☐ South Asia

- ☐ Western Africa
- ☐ The Sahel
- ☐ Eastern Africa
- ☐ Central Africa
- ☐ Southern Africa
- ☐ Northeast Asia
- ☐ Southeast Asia
- ☐ Central America & Caribbean Basin
- ☐ South America

**4 Are you satisfied with your current assignment?\***

Please choose **only one** of the following:

- ☐ Very Satisfied
- ☐ Satisfied
- ☐ Indifferent
- ☐ Unsatisfied
- ☐ Very Unsatisfied

**5 Let us pretend that the RCLF assignment was conducted randomly and your assignment is Arabian Peninsula and Gulf. How satisfied are you with this assignment?\***

Please choose **only one** of the following:

- ☐ Very Satisfied
- ☐ Satisfied
- ☐ Indifferent
- ☐ Unsatisfied

- ☐ Very Unsatisfied

**6 Which assignment process gave you the more desirable assignment?\***

Please choose **only one** of the following:

- ☐ Random assignment
- ☐ Proposed assignment model

**7 Due to limited number of slots for each region, not everyone will receive their first choice. At what point would you be indifferent to your assignment?\***

Please choose **only one** of the following:

- ☐ After my 4th choice
- ☐ After my 7th choice
- ☐ After my 10th choice
- ☐ After my 14th choice

**8 Do you think the Marine Corps should take Marines' preferences into considerations?\***

Please choose **only one** of the following:

- ☐ Yes
- ☐ No

**9 Can you explain your position?**

Please write your answer here:

\* Denotes a mandatory field

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